A Necking Origin for Ganymede Long Wavelength Grooved Terrain Topography: Insights from Galileo Observations at Uruk Sulcus Geoffrey C. Collins[1], James W. Head[1], Robert T. Pappalardo[1], and the Galileo Imaging Team. [1]Brown University, Dept. of Geological Sciences, Providence, RI 02912, Geoffrey_Collins@brown.edu.

Based on interpretation of Voyager images, the formation of grooves in Ganymede's bright terrain has been variously attributed to open tension fractures or graben [1], or extensional structures formed as a result of ductile necking instabilities [2]. Analysis of short wavelength (<2 km) grooves in recent Galileo images of Uruk Sulcus indicates that the most recent grooves seem to be formed by tilt-block extensional faulting [3]. During the second close flyby of Ganymede by the Galileo spacecraft, stereo images were obtained of one of these tilt-block domains. The resulting topographic data [4] indicates that the tilt-block ridges are superimposed on broader ridges and troughs which correspond to the 6-7 km wavelength grooves observed in Voyager data of this area (figure 1). We argue that this long wavelength topography is created by extensional necking, with the tilt-block normal faults being the mechanism by which this brittle layer deforms plastically.

Fink and Fletcher [2] proposed that bright grooved terrain on Ganymede may be the result of extensional necking of a brittle layer overlying a ductile substrate of ice. This instability will amplify a preferred wavelength of topographic variation as the ductile layer flows toward areas of thinner overlying lithosphere. The amplification of topography caused by extensional necking will occur after extension has thinned the lithosphere enough to create a high thermal gradient, and thus a shallow brittle/ductile transition. Herrick and Stevenson [5] modeled the possibility that Ganymede grooved terrain may be the result of such necking instabilities. Given the amount of extension thought to have occurred in grooved terrain (1-10%) based on Voyager interpretations [6], they concluded that necking was not a viable model to create these grooves, because the thermal gradient and strain rates required were unrealistically high. Dombard and McKinnon [7] added a diffusional creep mechanism to change the rheology of this model, and found that necking could occur at lower temperature gradients and strain rates.

The discovery in the Galileo images of closely spaced tilt blocks provides new insight into the total amount of strain which occurred in these groove domains. Figure 2 (from [5]) shows a plot of temperature vs. strain rate for Ganymede, with a surface temperature of 120°K, and contours of two variables. The first variable is the wavelength of the topography being amplified, and the other is a factor q_d describing the growth rate of the instability. In the Galileo Uruk Sulcus stereo target area, the wavelength of the amplified topography is measured as 6-7 km, and q_d must be estimated in order to evaluate the feasibility of the model.

$$q_d = 1 + \ln(A/A_o)/\epsilon \qquad (1)$$

where A is the observed topographic variation between the ridges and troughs, A_o is the original topographic variation at this wavelength (generally assumed not to exceed a few meters), and ϵ is the total strain which the terrain was subject to during this extensional episode. The long wavelength ridges and troughs in Uruk Sulcus are 250-500 meters in relief, so A/A_o (the amplification of original topography by necking) can be estimated as ~100.

To estimate the strain which the grooved terrain in the stereo target area has undergone, a transect of the small scale ridges and troughs was taken across the area. For each tilt block, the trough-to-trough distance was determined, which approximates the spacing of the faults as they outcrop on the surface today. Then the position of the ridge crest was estimated from the stereo images and corrected for foreshortening due to the spacecraft viewing angle. It was found that the north facing slopes were an average of 1.5 times longer than the south facing slopes. In a tilt-block geometry, we assumed that the longer slopes represent the original surface, while the shorter slopes are the fault scarps. The average throw on these faults is thus 2/3 the fault spacing. The total extensional strain across this transect is:

$$\epsilon = \sin\delta / \sin[\delta - \tan^{-1}(\sin\delta / (\sin\delta + 3/2))]$$

where δ is the original dip of the faults, so $\epsilon \approx 0.45\text{-}0.55$ for fault dips of 60°-45°.

The total amount of extensional strain estimated for this area can be inserted into equation (1) to derive estimates of the growth factor q_d, ~9-11. Plotting these values on the graph in figure 2 (shaded area), we can estimate a temperature gradient of ~25-35°K/km and a strain rate of 10^{-11} to $10^{-12}\,\text{s}^{-1}$, which would form these grooves in 10^3-10^4 years. These conditions would imply a lithosphere only ~2 km thick at the time of extension. Using the Dombard and McKinnon model [7], these results indicate a temperature gradient of ~20-25°K/km and a strain rate of ~$10^{-14}\,\text{s}^{-1}$, forming the grooves in a span of 10^6 years.

Two wavelengths of ridges and troughs are observed in the Galileo Uruk Sulcus stereo target area. The longer wavelength of deformation could be caused by ductile necking, while the shorter wavelength is the corresponding brittle deformation of the lithosphere. If this is the case, the extensional episode occurred in an area of 2 km thick lithosphere and lasted for thousands up to tens of thousands of years, using the parameters of the Herrick and Stevenson model. The correlation of grooves observed at Voyager scale to these necking features will allow mapping of these conditions outside the stereo area, to gain a broader view of the state of the lithosphere during the formation of grooved terrain.

Extensional Necking of Ganymede Grooved Terrain: Collins et al.

References: [1] Squyres, S. W. (1982) *Icarus* 52, 545-559; [2] Fink, J. H., and R. C. Fletcher (1981) *NASA TM-84211*, 51-53; [3] Pappalardo, R. T. *et al.* (1997) this volume; [4] Giese, B. *et al.* (1997) this volume; [5] Her-rick, D. L., and D. J. Stevenson (1990) *Icarus* 85, 191-204; [6] McKinnon, W. B. (1981) *LPSC XII*, 1585-1597; [7] Dombard, A. J., and W. B. McKinnon (1996) *LPSC XXVII*, 317-318.
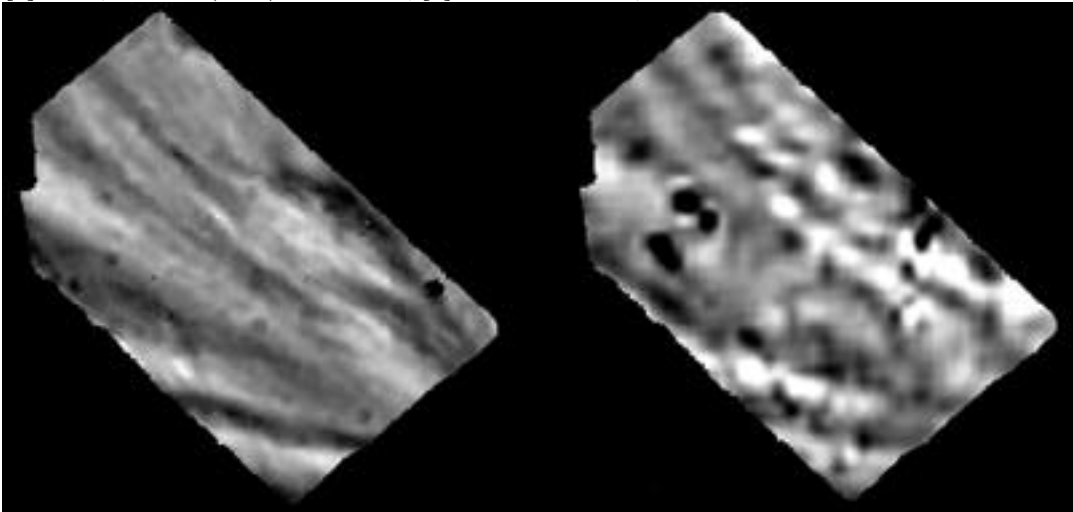

Figure 1: Comparison of digital elevation model [4] (left, 0.2 km/pixel) to Voyager 2 clear filter image (right, 1.1 km/pixel) of Galileo Uruk Sulcus stereo target area. Dark areas on the DEM indicate lower elevation, Voyager image shows albedo. Note the correspondence of albedo stripes to the long wavelength topography.
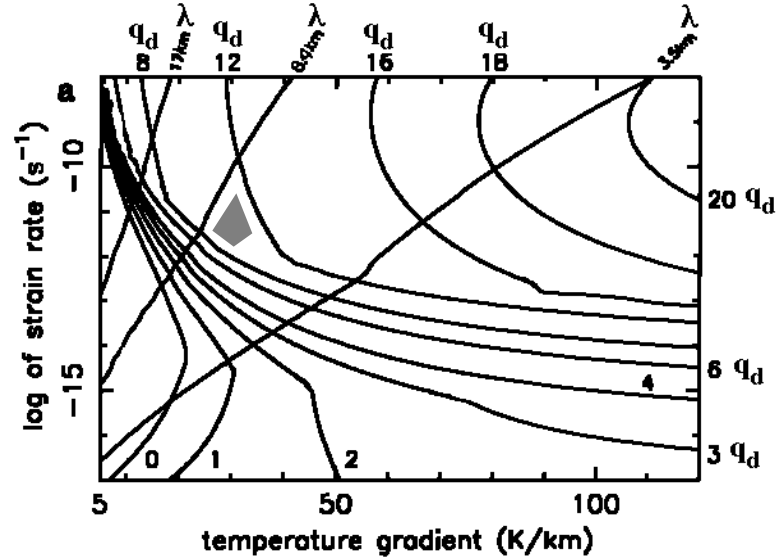

Figure 2: Graph of strain rate vs. temperature gradient with contours of wavelength ( ) and q_d for Ganymede conditions, modified from [5]. Shaded area represents range of values found in this study.